Analyst Perspective: The Coming Revolution in ICs: Intelligent, Integrated Microsystems

Mr. A.D. Romig, Jr.
Director, Microelectronics and Photonics
Mr. J.H. Smith
Team Leader, Intelligent Micromachiine Technology
Sandia National Laboratories
Albuquerque, NM

Tel: +1 (505) 844.3098
Fax: +1 (505) 844.2991
Website:www.mdl.sandia.gov/micromachine
email: j.h.smith@ieee.org

The next decade will see a revolution in the electronics industry in which the functionality of Integrated Circuits (ICs) grows beyond the traditional role of processing and storing data and controlling electrical functions. The intelligent microsystem revolution is the next step in the evolution of the electronics industry, and will begin to allow complex systems-on-a-chip to directly interact with their environment by sensing, actuating, and communicating without the need for external hardware.

The electronics industry is already evolving towards increased functionality on a single chip. For instance, the microprocessor/microcontroller has grown from a multi-chip set in the 1980s to a single chip that contains logic devices as well as static memory, non-volatile memory, and even dynamic memory in some cases. Similarly, mixed signal (analog/digital) functions did not appear in the marketplace until quite recently.

The intelligent, integrated microsystem revolution will be the next leap in functionality for the electronics industry. Figure 1 is an electron micrograph of a spider mite resting on an example of one of these devices, a set of mechanical gears made in a conventional IC foundry with conventional microelectronics manufacturing techniques and equipment.

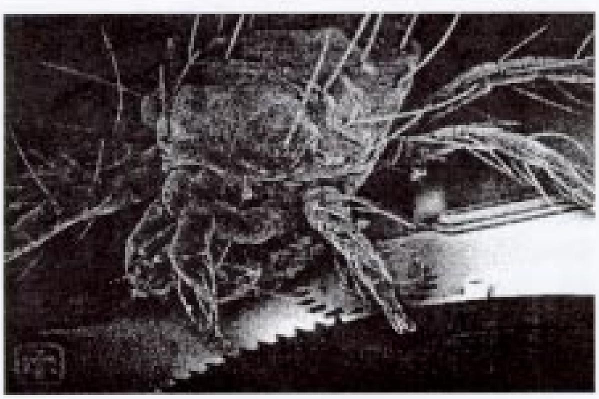

Figure 1. An electron micrograph of a spider mite sitting on a set of polysilicon gears.

The market for microsystems based on semiconductor processing began to emerge in the 1970s with the introduction of the bulk micromachined pressure sensor. Today, these pressure sensors see applications as diverse as in-vivo blood pressure monitoring and automotive manifold air pressure sensing. Figure 2 summarizes the projection of six different market studies for microsystems between 1995 and the year 2000. Although these studies differ somewhat because of varying definitions of the microsystem market itself, different cost growth models, and different groups surveyed (suppliers vs. end users), the clear trend among the projections is that the market has tremendous growth potential and will range from US $3 billion to $30 billion by the year 2000.

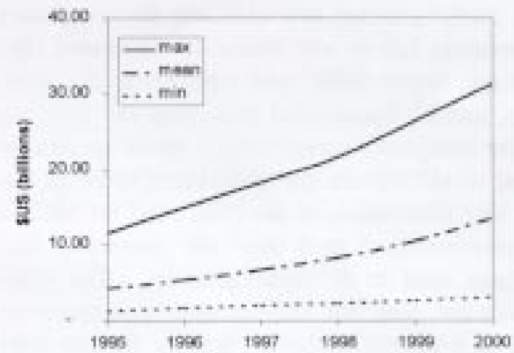

Figure 2. Minimum, mean, and maximum of projected market trends from six market studies for world microsystems market. It should be noted that these surveys use different approaches and assumptions for estimating the market as well as different definitions for that market. The trend that can be taken from these surveys is the tremendous size and growth potential for microsystems. (Source: Sid Marshall, Micromachined Devices, 1997.)

Microsystems technology heavily leverages developments made in semiconductor processing over the past decade. Although there are a variety of technologies that fall under the umbrella of microsystems, the vast majority of these technologies depend on the precision lithography and etching developed as part of the semiconductor industry. Some technologies such as polysilicon surface micromachining (first developed by R. Howe and colleagues at U.C. Berkeley) or the integration of these devices with microelectronic devices in a monolithic manufacturing process (commercially demonstrated by Analog Devices, Inc. with their ADXL-50 accelerometer) draw their manufacturing techniques entirely from the semiconductor area. Other techniques such as LIGA (a German acronym for lithography, electroforming, and injection molding) leverage only the lithography from the semiconductor world.

Microsystems or Intelligent, Integrated Systems (I^3S) are combinations of sensors (either chemical or physical or both), MicroElectromechanical Systems (MEMS), ICs, and miniature communications systems (RF, optical, etc.) Here, we will focus on the equipment and manufacturing needs for the subset of microsystems called IMEMS (Integrated MicroElectroMechanical Systems). IMEMS is essentially a combination of the MEMS and IC portions of the microsystem domain.

Equipment and material suppliers to the semiconductor industry need to be aware of this emerging technology, the manufacture of which requires their products. The time to begin to adapt to meet the needs of the manufacturers of microsystems is fast approaching. The basic differences between microsystem manufacturing and classical semiconductor manufacturing fall in two areas: 1.) Increased film thicknesses, aspect ratios, and topography of microsystems, and 2.) Specialized packaging and handling needs for completed components. More specific to the field of MEMS are the differences listed in Table 1. The thicknesses of the films used for MEMS are approximately 2 to 6 times the maximum film thicknesses used in IC manufacturing. The minimum feature size for the present generation of MEMS is 1 micron, although smaller feature sizes can be useful in some applications. The IC industry builds at feature sizes of 0.35 micron today and continues to push towards smaller critical dimensions. The desired aspect ratio of etches for MEMS and the topography resulting from the patterning of film stacks is much greater than found in IC manufacturing. Finally, as shown in Figure 3, the overall linear dimension of a MEMS component can be 100 microns or larger compared to the 1 micron linear dimension of today's microelectronic devices.

	ICs	MEMS
Film Thickness (μm)	<1	2-6
Critical Dimension (μm)	0.35	1
Aspect Ratio	2:1	6:1
Topography (μm)	<1	4-10
Device Size (μm)	1	100

Table 1. Comparison of characteristic thicknesses, dimensions, and sizes between typical IC devices and MEMS devices.

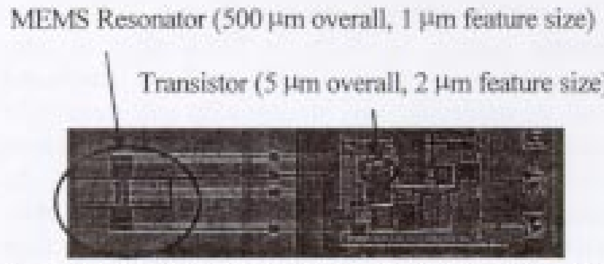

Figure 3. Comparison of device size and feature size for a MEMS device and a transistor manufactured in Sandia National Laboratories' IMEMS process.

The film thickness of MEMS and the resulting topography generate special needs for manufacturing equipment in the areas of film deposition, photolithography, etching, and planarization. Deposition equipment and processes must be able to accomodate the increased film thicknesses without excessive downtime for maintenance and cleaning. A single MEMS deposition can be equivalent in terms of maintenance requirements to ten depositions for an IC process. These films deposited with increased thickness must also be relatively low in stress and in stress gradient to prevent film delamination, dimensional changes, and curling of the final MEMS structures. Step coverage over the topography of previously deposited and patterned films is an issue as well as keyhole formation during the fill of high aspect ratio trenches.

MEMS generates special challenges in the photolithography area related to depth of focus, control of the focul plane itself, and photoresist coating/removal processes.

Dry etching equipment and processes for MEMS fabrication must deliver increased mask and stopping layer selectivity, increased etch rates, and high aspect ratio trenches. The elimination of stringers near topographical features is also an important consideration for etching equipment.

The use of planarization techniques such as Chemical Mechanical Polishing (CMP), spin-on-glass, deposition/etchback processes, and double LOCOS (LOCal Oxidation of Silicon) can help eliminate many of the topographical features of MEMS with a concomitant relaxation of the processing equipment requirements for those devices. CMP has proven to be particularly effective at increasing the manufacturability of MEMS devices in conventional IC processing equipment.

The final area of equipment development for the field of MEMS is in the release and packaging of the MEMS components. The final step in most MEMS manufacturing processes is the removal of a sacrificial film (usually silicon dioxide or photoresist) to free the moving mechanical structures of the MEMS device. Equipment for this removal and the subsequent handling of the released structures is a unique requirement to the field of MEMS.

In summary, the rapidly growing field of microsystems offers advantages over conventional products in the areas of cost, volume/weight, and reliability. Improvements in deposition, photolithography, and etching equipment and processes are needed to support this emerging field. New equipment and techniques are required for planarization, release, and packaging of MEMS components. These requirements offer new opportunities for equipment and material vendors to develop an additional market for their wares.

Further information about microsystems, MEMS, and links to other MEMS research program web pages can be found at Sandia's Micromachine Website: http://www.mdl.sandia.gov/micromachine

Acknowledgements:
This work was supported by the United States Department of Energy under contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.